



TITLE:

Acute effect and time course of extension and internal rotation stretching of the shoulder on infraspinatus muscle hardness

AUTHOR(S):

Kusano, Ken; Nishishita, Satoru; Nakamura, Masatoshi; Tanaka, Hiroki; Umehara, Jun; Ichihashi, Noriaki

CITATION:

Kusano, Ken ...[et al]. Acute effect and time course of extension and internal rotation stretching of the shoulder on infraspinatus muscle hardness. Journal of Shoulder and Elbow Surgery 2017, 26(10): 1782-1788

ISSUE DATE:

2017-10

URL:

<http://hdl.handle.net/2433/243914>

RIGHT:

© 2017. This manuscript version is made available under the CC-BY-NC-ND 4.0 license <http://creativecommons.org/licenses/by-nc-nd/4.0/>; This is not the published version. Please cite only the published version.; この論文は出版社版ではありません。引用の際には出版社版をご確認ご利用ください。

Effect of static stretching on infraspinatus

Acute effect and time course of extension and internal rotation stretching of the shoulder
on infraspinatus muscle hardness

Ken Kusano¹⁾, Satoru Nishishita¹⁾, Masatoshi Nakamura²⁾, Hiroki Tanaka³⁾, Jun
Umehara³⁾, Noriaki Ichihashi¹⁾

¹⁾ Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Shogoin-
Kawahara-cho, Kyoto 606-8507, Japan

²⁾ Institute for Human Movement and Medical Sciences, Niigata University of Health and
Welfare, Japan

³⁾ Rehabilitation Unit, Kyoto University Hospital, Kyoto, Japan

***Corresponding author:**

Ken Kusano (✉)

Human Health Sciences, Graduate School of Medicine, Kyoto University

53 Shogoin-Kawahara-cho, Sakyo-ku, Kyoto 606-8507, Japan

Telephone: +81-75-751-3935; Fax: +81-75-751-3909

E mail: kusano.ken.82u@st.kyoto-u.ac.jp

Acknowledgements

We would like to thank Ms. Ibuki and Editage (www.editage.jp) for English language
editing. Additionally, this study was supported by the Grant – in – Aid for Scientific
Research (B) 15H03043.

IRB

This study has been approved by the Ethics Committee of the Kyoto University

Effect of static stretching on infraspinatus

25 Graduate School and Faculty of Medicine: No. R0314.

26 **Conflict of Interest**

27 None.

Effect of static stretching on infraspinatus

28 **Abstract**

29 *Background:* A decrease in flexibility of the infraspinatus muscle causes limitations in the
30 range of shoulder motions. Static stretching (SS) is a useful method to improve muscle
31 flexibility and joint mobility. Previous researchers investigated effective stretching
32 methods for the infraspinatus. However, few researchers investigated the acute effect of
33 SS on the infraspinatus muscle's flexibility. In addition, the minimum SS time required
34 to increase the infraspinatus muscle's flexibility remains unclear. The aims of this study
35 included investigating the acute effect of SS on the infraspinatus muscle's hardness (an
36 index of muscle flexibility) by measuring shear elastic modulus and determining
37 minimum SS time to decrease the infraspinatus muscle's hardness.

38 *Methods:* This included measuring the effect of SS with extension and internal rotation
39 of the shoulder on the infraspinatus muscle's hardness in 20 healthy men. Hence, shear
40 elastic modulus of the infraspinatus was measured by ultrasonic shear wave elastography
41 before and after every 10 seconds up to 120 seconds of SS.

42 *Finding:* Two-way analysis of variance indicated a significant main effect of SS duration
43 on shear elastic modulus. The post hoc test indicated no significant difference between
44 shear elastic modulus after 10 seconds of SS and that before SS. However, shear elastic
45 modulus immediately after a period ranging from 20 seconds to 120 seconds of SS was
46 significantly lower than that before SS.

47 *Interpretation:* The results suggested that shoulder extension and internal rotation SS
48 effectively decreased the infraspinatus muscle's hardness. In addition, the results
49 indicated that a period exceeding 20 seconds of SS decreased the infraspinatus muscle's
50 hardness.

Effect of static stretching on infraspinatus

51 ***Word count***52 *3136words*

53

54 ***Keywords***

55 Ultrasonic shear wave elastography

56 Shear elastic modulus

57 Infraspinatus

58 Stretching

59 Shoulder

60 Shoulder extension stretching

61 Minimum stretching time

Effect of static stretching on infraspinatus

1 Introduction

Rotator cuff muscles play an important role in shoulder function because these muscles contribute to the dynamic stability of a shoulder joint³. Decrease in soft tissue flexibility of the posterior shoulder region, including the infraspinatus, teres minor, and posterior glenohumeral joint capsule, is defined as posterior shoulder tightness^{4, 27}. Several researchers have indicated that posterior shoulder tightness causes glenohumeral internal rotation deficit (GIRD) and limited range of motion (ROM) in the internal rotation of the shoulder^{9, 22}. A few others investigated the relationship between shoulder injuries and the manifestations of GIRD^{8, 26}. The researchers indicated that the manifestations of GIRD are linked to nonspecific shoulder pain⁸, and those affected are at high risk for the development of shoulder pathologic processes²⁶. Some reports have shown that treatment of GIRD with physical therapy improves flexibility of the posterior shoulder muscles^{1, 4}.

In general, static stretching (SS) is recommended as an effective intervention to increase muscle flexibility and joint ROM. Specifically, SS is an effective method that prevents joint contracture, decreases muscle strain, and improves muscle flexibility. Several prior studies have shown that maximum ROM increased immediately after SS^{5, 6} and that the passive torque or muscle-tendon unit stiffness decreased after SS^{7, 13}. However, it is not possible to assess the flexibility of individual muscles in the shoulder using these traditional measurements, such as passive torque and muscle stiffness, because of the complex shoulder joint construction and also because of the fact that ROM is affected by pain and stretch tolerance.

Researchers recently assessed muscle hardness as an index of muscle flexibility using ultrasonic shear wave elastography^{2, 17, 29, 31}. Ultrasonic shear wave elastography enables reliable measurement of local tissue in vivo. Several authors used shear elastic modulus

Effect of static stretching on infraspinatus

measured by ultrasonic shear wave elastography and investigated the effect of SS on muscle hardness,^{18, 28}. In addition, Nakamura et al delineated a significant correlation between rate of change in shear elastic modulus and rate of change in muscle stiffness¹⁸. Furthermore, Roskopf et al determined that ultrasonic shear wave elastography is reproducible to assess the shoulder muscles²⁴. Therefore, the effect of SS on shoulder muscle hardness could be assessed using ultrasonic shear wave elastography.

To stretch muscles effectively, it is important to define appropriate SS positions and a minimum length of time required for SS to increase muscle flexibility. Several researchers suggested SS positions for shoulder muscles based on kinesiology and anatomy^{16, 33}. A previous cadaveric study showed that the middle portion of the infraspinatus is most stretched in internal rotation with shoulder extension, and the inferior portion of this muscle is most stretched in internal rotation during shoulder elevation as well as during shoulder extension¹⁶. Therefore, we concluded that shoulder internal rotation with extension or elevation is the effective SS position for the infraspinatus muscle. In addition, the minimum time required for SS to increase infraspinatus muscle flexibility remains unclear. Determination of appropriate SS time could be useful for clinical sites and preparatory activities (exercise and warm-up). A few researchers have examined the minimum time for SS of the lower limbs^{19, 20}. However, no researchers have examined the minimum time required for SS for upper limb muscles. The SS minimum time required to increase muscle flexibility could differ across the muscles. The aim of this study included investigating the acute effect of SS on infraspinatus muscle hardness and identifying the minimum time required to decrease infraspinatus muscle hardness.

Effect of static stretching on infraspinatus

2 Methods

2.1 Subjects

Twenty healthy men with no previous history of orthopedic disease in the shoulder (age, 22.7 ± 1.5 years) were recruited for this study. Each subject provided written informed consent before taking part in the study. The sample size required for a 2-way analysis of variance (ANOVA) with repeated measures (effect size = 0.25 [medium], α error = .05, and power = 0.95) was calculated using G* power 3.1 software (Heinrich Heine University, Duesseldorf, Germany). We used G* power to calculate the necessary sample size based on the effect size, α error, and power. Elicited results have suggested that 17 subjects were required for the current study.

2.2 Experimental protocol

A crossover trial design was adopted to investigate the effect of stretching position on the decrease in muscle hardness. All subjects participated in both the stretching condition and the control condition. A set of the stretching condition consisted of 10 seconds of SS and a 30-second period during which the shear elastic modulus of the infraspinatus muscle was measured. Subjects participated in 12 consecutive sets (total SS time 120 seconds). A set in the control condition involved the subject's relaxing in a prone position for 10 seconds with the subject's upper limbs against the body and a 30-second period to measure shear elastic modulus. Subjects participated in 12 sets. Shear elastic modulus of the infraspinatus was measured before SS (SS0) and 12 times immediately after SS (SS1-SS12), thereby corresponding to a total of 13 times in the study.

2.3 Measurement of the shear elastic modulus

Effect of static stretching on infraspinatus

Ultrasonic shear wave elastography (Aixplorer, SuperSonic Imagine, Aix-en-Provence, France) with a SuperLinear SL 10–2 probe was used to assess the shear elastic modulus of the superior portion of the infraspinatus muscle in the nondominant shoulder. Some subjects had experience in participating in overhead sports. Therefore, we choose the nondominant side to examine only the effect of SS on infraspinatus muscle hardness. The position for measuring the shear elastic modulus of the infraspinatus muscle was termed as the prone position, in which subjects placed their hands behind their backs and brought thumb tips in line with the eighth thoracic vertebra (Fig. 1). The measurement site was defined as the intersection point of 2 lines; 1 line connected a point at the top fourth from the medial margin of spine of the scapula to the inferior angle of the scapula and greater tubercle, and the other line connected the middle point of the spine of the scapula and the inferior angle of the scapula (Fig. 2). These lines were marked on the skin with the subject prone, and the muscle belly was then specifically marked. The probe was placed parallel to the muscle fiber, and it was confirmed that the muscle fiber was uninterrupted on the ultrasonic image.

The calculation of the shear elastic modulus was based on previous studies^{18,21}. The shear elastic modulus was calculated from the mean shear wave speed within the region of interest. This process was automatically computed by ultrasonic shear wave elastography. All measurements of shear elastic modulus were performed by the same investigator. The shear elastic modulus was measured 3 times, and the mean value was used for the analysis. Each measurement was performed in a period of < 30 seconds to prevent the effect of measurement position on infraspinatus muscle hardness. Nakamura et al. indicated a significant correlation between rate of change in shear elastic modulus and rate of change in muscle stiffness¹⁸.

Effect of static stretching on infraspinatus

156

157 *2.4 Measurement reliability of the shear elastic modulus*

158 The reliability of the shear elastic modulus measurement was calculated using intraclass
159 correlation (1.1) for the 3 measurements at SS0 in the control condition.

160

161 *2.5 Measurement of range of ROM*

162 A digital angle gage (WR300; Wixey, Sanibel, FL, USA) was used to measure passive
163 ROM of internal rotation in the shoulder at SS0 and SS12. The ROM measurement of
164 internal rotation was performed with the shoulder at 90° abduction and the elbow at 90°
165 flexion at the prone position. Each measurement was performed 3 times, and the mean
166 values were used for analysis. The maximum ROM of internal rotation was defined as
167 the angle at which the inferior angle of the scapula began to move.

168

169 *2.6 Stretching position*

170 Extension and internal rotation SS of the shoulder was performed using a previously
171 defined position to stretch the middle and inferior portion of the infraspinatus muscle ¹⁶.
172 The nondominant upper limb was chosen for the SS. The SS starting position was defined
173 as the prone position, in which subjects placed their nondominant hands behind the back
174 with their palms facing upward. In the study, the investigator stabilized the scapula with
175 1 hand while cranially moving the subject's nondominant upper limb along the spine (Fig.
176 3). The stretching was performed to the maximum height that could be achieved by the
177 subject without discomfort or pain.

178

179 *2.7 Statistical analysis*

Effect of static stretching on infraspinatus

180 Statistical analysis was performed using SPSS (version 18.0; SPSS Japan Inc., Tokyo,
181 Japan). To investigate the effect of SS on infraspinatus muscle hardness and ROM of
182 internal rotation of the shoulder, differences in shear elastic modulus and ROM SS0 and
183 SS1-SS12 were assessed by a 2-way ANOVA with repeated measures using a 2-factor
184 (SS intervention [stretching vs. control]×measurement duration [13 conditions]) design.
185 The differences of the shear elastic modulus between SS0 and SS1-SS12 were determined
186 using Dunnett post hoc test when a significant interactive effect was found. The
187 differences of ROM of internal rotation between SS0 and SS12 were determined using
188 the paired Student t-test. A significance level of .05 was used in all the statistical tests.

Effect of static stretching on infraspinatus

3 Results

3.1 Measurement reliability

The reliability of the shear elastic modulus for the 3 measurements at SS0 in the control condition corresponded to intraclass correlation (1.1) of 0.939 (95% confidence interval, 0.879-0.973), which was significant.

3.2 Comparison of shear elastic modulus and ROM

The shear elastic modulus of each measurement time is shown in Table 1 as a mean \pm standard deviation. The results of the 2-way ANOVA indicated a significant main effect of measurement duration, with significant interaction between SS intervention and measurement duration. The post hoc test indicated that there were no significant differences between SS0 and SS1-SS12 with respect to shear elastic modulus in the control condition. In addition, there was no significant difference between SS0 and SS1 with respect to shear elastic modulus in the stretching condition. However, shear elastic modulus at SS2-SS12 were significantly lower than that at SS0 in the stretching condition.

The ROM of internal rotation at SS0 and SS12 is shown in Table 2 as mean \pm standard deviation values. The results of the 2-way ANOVA indicated a significant main effect of measurement duration with significant interaction between SS intervention and measurement duration. The post hoc test indicated no significant difference between SS0 and SS12 with respect to internal rotation ROM in the control condition. However, the results indicated that internal rotation ROM at SS12 was significantly greater than that at SS0 in the stretching condition.

Effect of static stretching on infraspinatus

4 Discussion

In the study, shear elastic modulus of the infraspinatus muscle was significantly lower and internal rotation ROM was greater after 120 seconds of SS when compared with that before SS. This was the first study to investigate the acute effect of extension and internal rotation SS of the shoulder on the infraspinatus muscle's hardness and ROM by using shear elastic modulus measured via ultrasonic shear wave elastography. Several previous authors examined the effect of SS on decrease in posterior shoulder tightness. Many researchers have used SS with the arm in an elevated position (e.g., the cross-body stretch), in which the shoulder was horizontally adducted ¹⁴ or sleeper stretch, in which the shoulder was internally rotated ¹². However, a previous cadaveric study showed that middle portion of the infraspinatus muscle was most stretched during internal rotation with shoulder extension. In addition, the inferior portion was also stretched in this position and did not exhibit any significant differences from internal rotation in elevation ¹⁶. Hence, the infraspinatus could be stretched more effectively by SS using extension compared with that with respect to SS at elevation.

Previous researchers indicated that ROM of internal rotation and horizontal adduction in the shoulder increased immediately after 60 seconds or 180 seconds of SS ^{12, 23} and that the infraspinatus muscle's hardness decreased immediately after 150 seconds of cross-body stretch³⁰ or after a 4 week SS intervention ³⁴. The findings in this study confirmed the effect of extension and internal rotation SS by directly measuring the muscle hardness and indicated that decrease in the infraspinatus muscle's hardness was observed 20 seconds after the initiation of SS. Therefore, it is probably necessary to stretch for at least 20 seconds in order to decrease the infraspinatus muscle's hardness.

A few publications indicated that the time required for effective SS in the lower limbs

Effect of static stretching on infraspinatus

is 2.5 minutes²⁰ or 7.5 minutes¹³. These time periods are sufficient in decreasing the passive torque and muscle-tendon unit stiffness of the hamstrings. Nevertheless, the infraspinatus muscle's hardness was decreased immediately after 20 seconds of SS in this study. A potential reason for the shorter times of SS in this study compared with that in previous studies could be the differences in muscles structure (size, physiological cross-sectional area [PCSA], and fascicle angles), stabilization of the scapula, and the use of shear elastic modulus as an index of muscle hardness.

The referred researchers examined the effective time needed for SS of the lower limbs^{13, 20}. However, in this study, we examined the effective time needed for SS of the infraspinatus muscle. The PCSA of the infraspinatus muscle is very small compared with that of the hamstrings^{10, 11}. It was hypothesized that muscle tension per PCSA would increase if the PCSA of the muscle decreased and the tension applied by SS was equal. Therefore, the reason for the decrease in the infraspinatus muscle's hardness with respect to shorter SS time could be explained by the large muscle tension per PCSA. In addition, researchers have shown that scapular stabilization during the cross-body stretch increased the effects of stretching on the posterior glenohumeral joint ROM³² and the infraspinatus muscle's hardness³⁰. In this study, the infraspinatus muscle could be effectively stretched because of the stabilization of the scapula during SS. In addition, the shear elastic modulus was used as an index of muscle hardness instead of ROM. In general, the effects of SS were calculated using ROM as an index of joint flexibility. However, several researchers indicated that the assessment of ROM is inadequate in evaluating muscle flexibility because maximum ROM measurements are influenced by pain and stretch tolerance^{15, 25}. In contrast, the shear elastic modulus is calculated using the shear wave propagation speed within the muscle belly. Therefore, the shear elastic modulus assessed

Effect of static stretching on infraspinatus

260 muscle hardness. In this respect, the shear elastic modulus might be more sensitive to
261 muscle hardness compared with ROM.

262 The results indicated that there may be differences in the minimum SS time required
263 to decrease muscle hardness among muscles. In the future, it is necessary to investigate
264 the acute effect of SS on the hardness of various muscles and to reveal the relationship
265 between the minimum SS time required to decrease muscle hardness and muscle
266 structures.

267 This study has a few limitations. First, it was not possible to compare muscle tension
268 during SS in the study with previous literature because of differences in muscle flexibility
269 indices. Second, only the acute effect of SS was examined, and therefore the effect of a
270 long term SS intervention program is unclear. Third, the subjects in this study were
271 healthy young men. Equivalent acute effects of SS cannot be consistently expected in
272 older people and patients with shoulder symptoms. Further research is required to
273 investigate the intervention effect of SS in older people and patients with shoulder
274 symptoms to facilitate clinical application. Fourth, only the nondominant extremity was
275 assessed in this study. So, the effect of SS on the overhead sports player with restriction
276 in ROM of the dominant shoulder is unclear. Fifth, this study protocol was repeated
277 measures. No repeated measure was required to determine if this change was only
278 temporary or maintained.

Effect of static stretching on infraspinatus

279 **5 *Conclusions***

280 The results of this study indicated that the infraspinatus muscle's hardness is decreased
281 whereas ROM of internal rotation is increased immediately after internal rotation and
282 extension SS of the shoulder. Furthermore, the findings suggested that the infraspinatus
283 muscle's hardness decreased after a minimum of 20 seconds of SS.

284

285

286

287

Effect of static stretching on infraspinatus

288

289 *References*

- 290 1. Bailey LB, Shanley E, Hawkins R, Beattie PF, Fritz S, Kwartowitz D et al.
291 Mechanisms of Shoulder Range of Motion Deficits in Asymptomatic Baseball
292 Players. *Am J Sports Med* 2015;43:2783-2793. 10.1177/0363546515602446
- 293 2. Bercoff J, Tanter M, Muller M, Fink M. The role of viscosity in the impulse
294 diffraction field of elastic waves induced by the acoustic radiation force. *IEEE Trans*
295 *Ultrason Ferroelectr Freq Control* 2004;51:1523-1536.
- 296 3. Boettcher CE, Cathers I, Ginn KA. The role of shoulder muscles is task specific. *J*
297 *Sci Med Sport* 2010;13:651-656. 10.1016/j.jsams.2010.03.008
- 298 4. Borsa PA, Wilk KE, Jacobson JA, Scibek JS, Dover GC, Reinold MM et al.
299 Correlation of range of motion and glenohumeral translation in professional baseball
300 pitchers. *Am J Sports Med* 2005;33:1392-1399. 10.1177/0363546504273490
- 301 5. de Weijer VC, Gorniak GC, Shamus E. The effect of static stretch and warm-up
302 exercise on hamstring length over the course of 24 hours. *J Orthop Sports Phys Ther*
303 2003;33:727-733. 10.2519/jospt.2003.33.12.727
- 304 6. Depino GM, Webright WG, Arnold BL. Duration of maintained hamstring flexibility
305 after cessation of an acute static stretching protocol. *J Athl Train* 2000;35:56-59.
- 306 7. Fowles JR, Sale DG, MacDougall JD. Reduced strength after passive stretch of the
307 human plantarflexors. *J Appl Physiol* (1985) 2000;89:1179-1188.
- 308 8. Giles K, Musa I. A survey of glenohumeral joint rotational range and non-specific
309 shoulder pain in elite cricketers. *Phys Ther Sport* 2008;9:109-116.
310 10.1016/j.ptsp.2008.03.002
- 311 9. Grossman MG, Tibone JE, McGarry MH, Schneider DJ, Veneziani S, Lee TQ. A
312 cadaveric model of the throwing shoulder: a possible etiology of superior labrum
313 anterior-to-posterior lesions. *J Bone Joint Surg Am* 2005;87:824-831.
314 10.2106/JBJS.D.01972
- 315 10. Klein Horsman MD, Koopman HF, van der Helm FC, Prosé LP, Veeger HE.
316 Morphological muscle and joint parameters for musculoskeletal modelling of the
317 lower extremity. *Clin Biomech* (Bristol, Avon) 2007;22:239-247.
318 10.1016/j.clinbiomech.2006.10.003
- 319 11. Langenderfer JE, Patthanacharoenphon C, Carpenter JE, Hughes RE. Variability in
320 isometric force and moment generating capacity of glenohumeral external rotator
321 muscles. *Clin Biomech* (Bristol, Avon) 2006;21:701-709.
322 10.1016/j.clinbiomech.2006.02.010

Effect of static stretching on infraspinatus

- 323 12. Laudner KG, Sipes RC, Wilson JT. The acute effects of sleeper stretches on shoulder
324 range of motion. *J Athl Train* 2008;43:359-363. 10.4085/1062-6050-43.4.359
- 325 13. Magnusson SP, Simonsen EB, Aagaard P, Kjaer M. Biomechanical responses to
326 repeated stretches in human hamstring muscle in vivo. *Am J Sports Med*
327 1996;24:622-628.
- 328 14. Manske RC, Meschke M, Porter A, Smith B, Reiman M. A randomized controlled
329 single-blinded comparison of stretching versus stretching and joint mobilization for
330 posterior shoulder tightness measured by internal rotation motion loss. *Sports Health*
331 2010;2:94-100. 10.1177/1941738109347775
- 332 15. McHugh MP, Kremenik IJ, Fox MB, Gleim GW. The role of mechanical and neural
333 restraints to joint range of motion during passive stretch. *Med Sci Sports Exerc*
334 1998;30:928-932.
- 335 16. Muraki T, Aoki M, Uchiyama E, Murakami G, Miyamoto S. The effect of arm
336 position on stretching of the supraspinatus, infraspinatus, and posterior portion of
337 deltoid muscles: a cadaveric study. *Clin Biomech (Bristol, Avon)* 2006;21:474-480.
338 10.1016/j.clinbiomech.2005.12.014
- 339 17. Nakamura M, Hasegawa S, Umegaki H, Nishishita S, Kobayashi T, Fujita K et al.
340 The difference in passive tension applied to the muscles composing the hamstrings -
341 Comparison among muscles using ultrasound shear wave elastography. *Man Ther*
342 2016;24:1-6. 10.1016/j.math.2016.03.012
- 343 18. Nakamura M, Ikezoe T, Kobayashi T, Umegaki H, Takeno Y, Nishishita S et al. Acute
344 effects of static stretching on muscle hardness of the medial gastrocnemius muscle
345 belly in humans: an ultrasonic shear-wave elastography study. *Ultrasound Med Biol*
346 2014;40:1991-1997. 10.1016/j.ultrasmedbio.2014.03.024
- 347 19. Nakamura M, Ikezoe T, Takeno Y, Ichihashi N. Time course of changes in passive
348 properties of the gastrocnemius muscle-tendon unit during 5 min of static stretching.
349 *Man Ther* 2013;18:211-215. 10.1016/j.math.2012.09.010
- 350 20. Nordez A, Cornu C, McNair P. Acute effects of static stretching on passive stiffness
351 of the hamstring muscles calculated using different mathematical models. *Clin*
352 *Biomech (Bristol, Avon)* 2006;21:755-760. 10.1016/j.clinbiomech.2006.03.005
- 353 21. Nordez A, Gennissou JL, Casari P, Catheline S, Cornu C. Characterization of muscle
354 belly elastic properties during passive stretching using transient elastography. *J*
355 *Biomech* 2008;41:2305-2311. 10.1016/j.jbiomech.2008.03.033
- 356 22. Oyama S, Myers JB, Blackburn JT, Colman EC. Changes in infraspinatus cross-
357 sectional area and shoulder range of motion with repetitive eccentric external rotator
358 contraction. *Clin Biomech (Bristol, Avon)* 2011;26:130-135.

Effect of static stretching on infraspinatus

- 10.1016/j.clinbiomech.2010.09.018
23. Park KN, Kwon OY, Weon JH, Choung SD, Kim SH. Comparison of the effects of
local cryotherapy and passive cross-body stretch on extensibility in subjects with
posterior shoulder tightness. *J Sports Sci Med* 2014;13:84-90.
24. Roskopf AB, Ehrmann C, Buck FM, Gerber C, Flück M, Pfirrmann CW.
Quantitative Shear-Wave US Elastography of the Supraspinatus Muscle: Reliability
of the Method and Relation to Tendon Integrity and Muscle Quality. *Radiology*
2016;278:465-474. 10.1148/radiol.2015150908
25. Sale D, Quinlan J, Marsh E, McComas AJ, Belanger AY. Influence of joint position
on ankle plantarflexion in humans. *J Appl Physiol Respir Environ Exerc Physiol*
1982;52:1636-1642.
26. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA.
Shoulder range of motion measures as risk factors for shoulder and elbow injuries in
high school softball and baseball players. *Am J Sports Med* 2011;39:1997-2006.
10.1177/0363546511408876
27. Tyler TF, Roy T, Nicholas SJ, Gleim GW. Reliability and validity of a new method
of measuring posterior shoulder tightness. *J Orthop Sports Phys Ther* 1999;29:262-
269; discussion 270-264. 10.2519/jospt.1999.29.5.262
28. Umegaki H, Ikezoe T, Nakamura M, Nishishita S, Kobayashi T, Fujita K et al. Acute
effects of static stretching on the hamstrings using shear elastic modulus determined
by ultrasound shear wave elastography: Differences in flexibility between hamstring
muscle components. *Man Ther* 2015;20:610-613. 10.1016/j.math.2015.02.006
29. Umegaki H, Ikezoe T, Nakamura M, Nishishita S, Kobayashi T, Fujita K et al. The
effect of hip rotation on shear elastic modulus of the medial and lateral hamstrings
during stretching. *Man Ther* 2015;20:134-137. 10.1016/j.math.2014.07.016
30. Umehara J, Hasegawa S, Nakamura M, Nishishita S, Umegaki H, Tanaka H et al.
Effect of scapular stabilization during cross-body stretch on the hardness of
infraspinatus, teres minor, and deltoid muscles: An ultrasonic shear wave
elastography study. *Man Ther* 2016. 10.1016/j.math.2016.10.004
31. Umehara J, Ikezoe T, Nishishita S, Nakamura M, Umegaki H, Kobayashi T et al.
Effect of hip and knee position on tensor fasciae latae elongation during stretching:
An ultrasonic shear wave elastography study. *Clin Biomech (Bristol, Avon)*
2015;30:1056-1059. 10.1016/j.clinbiomech.2015.09.007
32. Wilk KE, Hooks TR, Macrina LC. The modified sleeper stretch and modified cross-
body stretch to increase shoulder internal rotation range of motion in the overhead
throwing athlete. *J Orthop Sports Phys Ther* 2013;43:891-894.

Effect of static stretching on infraspinatus

- 395 10.2519/jospt.2013.4990
- 396 33. Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the
- 397 overhead throwing athlete. Am J Sports Med 2002;30:136-151.
- 398 34. Yamauchi T, Hasegawa S, Nakamura M, Nishishita S, Yanase K, Fujita K et al.
- 399 Effects of two stretching methods on shoulder range of motion and muscle stiffness
- 400 in baseball players with posterior shoulder tightness: a randomized controlled trial. J
- 401 Shoulder Elbow Surg 2016;25:1395-1403. 10.1016/j.jse.2016.04.025
- 402

Effect of static stretching on infraspinatus

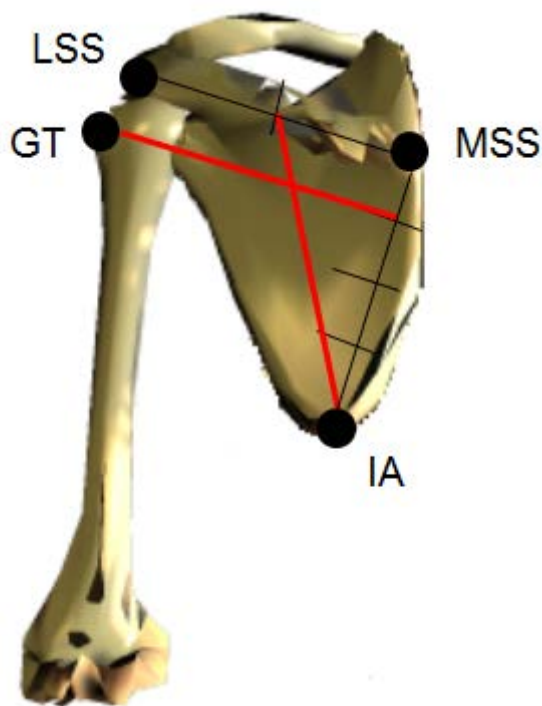
403 Figure 1. The position in which shear elastic modulus of the infraspinatus is measured.
404 One investigator placed the subject's hand behind the subject's back, and brought the tip
405 of the subject's thumb in line with the eighth thoracic vertebra in a prone position. The
406 other investigator measured shear elastic modulus of the infraspinatus with region of
407 interest matching at the center of muscle belly.



408

Effect of static stretching on infraspinatus

Figure 2. The site of measuring shear elastic modulus of the infraspinatus. The measurement site is defined as the intersection point of 2 lines. One line connects a point at the top fourth from the medial margin of spine of the scapula (MSS) to the inferior angle of the scapula (IA) and greater tubercle (GT). The other line connects the IA and the middle point between MSS and lateral margin of the spine of the scapula (LSS).



Effect of static stretching on infraspinatus

Figure 3. The static stretching position with internal rotation with extension of the shoulder. The nondominant upper limb is selected for the static stretching. The investigator places the subject's nondominant hand behind the subject's back with the subject's palm facing upwards. The investigator stabilizes the subject's scapula with 1 hand while moving the nondominant upper limb of the subject cranially with the other hand, such that a point at the maximum possible height on the subject's spine can be reached while ensuring that the back of the subject's hand remains adhered to the subject's back.



Effect of static stretching on infraspinatus

Table 1. Shear elastic modulus of the infraspinatus in the stretching duration from SS0 to SS12

| | Stretching | | | Control | | |
|------|---------------|---------|-------------|---------------|---------|-------------|
| | Shear elastic | P value | Effect size | Shear elastic | P value | Effect size |
| | Modulus | | | Modulus | | |
| | (kPa) | | | (kPa) | | |
| SS0 | 9.0±3.2 | | | 8.9±3.3 | | |
| SS1 | 8.2±3.0 | .288 | 0.27 | 9.4±2.9 | 1.0 | 0.01 |
| SS2 | 7.7±3.2 | .012 | 0.43 | 9.2±3.2 | 1.0 | 0.05 |
| SS3 | 7.8±3.0 | .032 | 0.40 | 9.2±3.6 | 1.0 | 0.05 |
| SS4 | 7.5±2.4 | .002 | 0.56 | 9.4±3.6 | .660 | 0.15 |
| SS5 | 7.9±2.6 | .046 | 0.40 | 9.2±3.1 | .999 | 0.07 |
| SS6 | 7.4±2.5 | .002 | 0.55 | 9.0±3.0 | .835 | 0.13 |
| SS7 | 7.9±2.3 | .046 | 0.42 | 9.2±4.0 | .999 | 0.06 |
| SS8 | 7.4±2.7 | .001 | 0.56 | 9.1±3.3 | .997 | 0.07 |
| SS9 | 7.6±3.0 | .005 | 0.48 | 9.5±3.2 | 1.0 | 0.02 |
| SS10 | 7.6±2.3 | .006 | 0.52 | 9.5±3.4 | 1.0 | 0.03 |
| SS11 | 7.3±2.6 | .001 | 0.58 | 9.0±3.0 | .927 | 0.11 |
| SS12 | 7.6±2.5 | .005 | 0.52 | 9.5±3.8 | 1.0 | 0.02 |

432

433 SS, static stretching.

434 P value and effect size of SS1-SS12 compared with SS0.

435 Values are expressed as mean value ± standard deviation. The effect size of SS1-SS12

436 with respect to SS0 represents Cohen's d values.

Effect of static stretching on infraspinatus

Table 2. Range of motion of internal rotation in the shoulder at 90° abduction with the elbow in 90° flexion at SS0 and SS12.

| | Stretching | | | Control | | |
|------|---------------------|---------|-------------|---------------------|---------|-------------|
| | Range of motion (°) | P value | Effect size | Range of motion (°) | P value | Effect size |
| SS0 | 61±8 | | | 66±9 | | |
| SS12 | 65±9 | .001 | 0.52 | 66±9 | .287 | 0.08 |

SS, static stretching

P value and effect size of SS12 compared with SS0.

Values are expressed as mean value ± standard deviation. The effect size of SS12 with respect to SS0 represents Cohen's d values.